DISTRIBUTION OF MARINE BIRDS IN RELATION TO WATER MASSES AND FRONTS IN THE STRAIT OF BELLE ISLE, NORTHWESTERN ATLANTIC OCEAN

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Distribution of marine birds in relation to water masses and fronts in the Strait of Belle Isle, northwestern Atlantic Ocean

by

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Abstract

The Strait of Belle Isle, which separates the Northern Peninsula of Newfoundland and mainland Canada, is a region of two water masses, moving in opposite directions, separated by a seasonal frontal boundary. There are major seasonal migrations of marine mammals, birds and fishes through the Strait. Cold water from the Labrador Current enters the Strait along the Labrador coast and moves into the Gulf of St. Lawrence along the North Shore of Quebec. Warm water flows out of the Gulf of St. Lawrence through the Strait of Belle Isle along the western Newfoundland coast. These different water masses along the two sides of the Strait are associated with different seabird colonies, i.e. pursuit-diving alcids and pelagic kittiwakes nesting along the Quebec South Shore and only a few colonies of surface-feeding gulls and terns on the Newfoundland coast. Furthermore, a previous study (Rees 1963) reported that Thick-billed Murres were associated with the cold Labardor Current water mass and pursuit-diving alcids were associated with the frontal regions in the Strait of Belle Isle. However, no subsequent studies have been conducted on seabird distributions in relation to fronts in the Strait of Belle Isle.

The present study investigated seasonal patterns of seabird abundance in the Strait of Belle Isle. Ship and land-based surveys were conducted across and on both sides of the Strait in order to address three questions:

1) What are the abundance patterns of pursuit-diving alcids and pelagic surface-feeding gulls in the Strait of Belle Isle?

2) Do alcids occur more frequently in the cold water (western) region and gulls occur more frequently in the warm water (eastern) region?

3) Do seabirds occur more frequently near the frontal region of the Strait of Belle Isle?

It was also expected that the frontal water mass boundary would move over the season and would influence the distributions and abundances of seabirds. An independent data set of land-based observations from Point Amour, Labrador during spring 1996 was used to answer a fourth question:

4) Do wind conditions influence marine bird occurrences in the Strait, as has been reported in previous coastal studies?

Alcids and gulls were the dominant avian groups during the study. Some transects revealed statistically significant differences in seabird densities between eastern and western water masses but there was no consistently higher seabird density associated with either water mass. Seabird density was also not significantly higher at the frontal region. Differences in surface temperatures between eastern and western water masses and frontal strength varied monthly. Statistical simulations revealed that at the observed level of variance, it would not be possible to run sufficient surveys in a season to find significant differences in seabird densities between eastern and western water masses or between frontal and non-frontal regions. Gulls, loons and ducks showed decreases in abundance

immediately following wind events. In comparison, alcids showed a delayed positive correlation with longshore wind events, with maximum correlation occurring at a lag of 4 days. The results do not support the hypothesis that seabird occurrences are influenced by the presence of different water masses or frontal regions in the Strait of Belle Isle. Frontal occurrence in the Strait of Belle Isle may not aggregate prey for seabirds, as has been previously hypothesized. Power analysis should be undertaken before surveying seabirds relative to oceanographic processes or anthropogenic effects.

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Introduction

Patterns and changes in the physical, chemical and biological features of the oceanographic environment play a fundamental role in the distributions of marine birds and mammals. A major factor influencing marine bird and mammal distributions is availability and abundance of prey (Murphy 1936; Ashmole 1971; Schneider and Piatt 1986; Hunt and Schneider 1987; Burger 1988; Ryan and Cooper 1989). Prey species are in turn influenced by many biological and physical variables, such as competition, predation, ice, wind, fronts, water temperature, upwelling and their interactions (Bourne 1981; Schneider 1982; Blomqvist and Peterz 1984; Abrams and Miller 1986; Ainley *et al.* 1986; Bradstreet 1986; Pakhomov and McQuaid 1996).

Marine bird and mammal distributions have been related to water mass characteristics (Hunt 1991; Wooller *et al.* 1991). Fronts are regions of large gradients in water properties (e.g. density or temperature) over a relatively small spatial scale where water masses of different densities or thermoclines come into contact. Fronts tend to be regions of high physical and biological activity, due often to upwelling of colder, nutrient rich water. Such regions are often highly productive and provide a potentially rich prey source for tertiary level marine consumers. Frontal strength can be influenced by weather, current and tidal patterns and such regions sometimes attract large numbers of marine birds and mammals (Hunt 1991).

Two general hypotheses relate avian biological activity to fronts. One holds that enhanced primary production at fronts increases prey availability via increases in animal growth, reproduction, or immigration, and thereby attracts large numbers of marine birds. This hypothesis has yet to be evaluated, as it is unknown whether enhanced primary production at fronts is passed directly to higher tertiary levels or conveyed elsewhere (Schneider 1990). The second asserts that prey patches develop

at fronts due to behavioral responses of prey (low level consumers) to oceanographic (e.g. temperature or salinity) gradients or to the association (Schneider *et al.* 1987) or interaction (Schneider *et al.* 1990) between prey behavior and circulatory patterns. Following either of these hypotheses then, seabird and marine mammal activity should be higher at fronts due to prey concentrated by physical features. Many studies have found increased bird activity at fronts (e.g. Hunt *et al.* 1991; Lee 1993) and marine bird and mammal associations at feeding sites (e.g. Ridoux 1987; Joiris 1992; Woehler and Green 1992).

However, Schneider *et al.* (1987) found that although episodic aggregations of seabirds occur at fronts, seabird abundances are, on average, no higher at frontal regions than in adjacent open water regions. Also, a lack of marine birds or mammals at a front does not mean that the front is not productive.

The Strait of Belle Isle, northwest Atlantic Ocean, is one region displaying seasonal variation in frontal occurrence and activity. During spring, summer and fall, cold and warm water masses flowing on either side of the Strait form an interface. Upwelling drives the interface to the surface, forming a front. This interface moves westward as water throughout the Strait warms over the summer.

Numerous seabird colonies along the western side of the Strait of Belle Isle and along the Quebec North Shore are comprised mostly of pursuit-diving alcids and other cold water seabirds (Rees 1963; Cairns *et al.* 1989). These colonies are considered to be supported through the influences of a small inshore branch of the cold Labrador Current (Chapdelaine and Brousseau 1992). In contrast, the eastern side of the Strait is the site of warmer, slightly less saline water flowing out of the Gulf of St. Lawrence and supports only scattered colonies of surface-feeding gulls and terns

(Rees 1963; Cairns *et al.* 1989; Montevecchi and Anderson 1998). The seabird communities of the western side of the Strait of Belle Isle more closely resemble those of eastern Newfoundland than those of the eastern side of the Strait.

Zooplankton species distributions also differ sharply between eastern and western regions of the Strait. Sub-polar zooplankton (e.g. *Calanus* spp. and *Pseudocalanus* spp.) dominate the western region, while temperate species (e.g. *Temora longicornis*) are prominent in the east (Montevecchi 1996). These biological contrasts are striking and clearly reflect oceanographic differences across the Strait.

Wind events also influence marine bird movements (e.g. Jouventin and Weimerskirch 1990). Unlike land birds, pelagic seabirds do not have refuge from strong winds. To evade unfavorable wind conditions, these seabirds may use wave troughs for long distance flight, alternatively climbing against the wind over wave crests and descending back down into the trough (Blomqvist and Peterz 1984). Coastal seabirds tend to fly along coasts into headwinds (Bourne 1982; Blomqvist and Peterz 1984). Wind-induced coastal currents may induce nearshore upwelling, which can further enhance primary and secondary productivity and attract marine birds. Hence wind is expected to influence seabird distributions in coastal regions. The present study compared the distributional patterns of seabirds in the Strait of Belle Isle during the spring and fall of 1996 to address four questions:

1) What are the abundance patterns of pursuit-diving alcids and pelagic surface-feeding gulls in the Strait of Belle Isle?

2) Do alcids occur more frequently in the cold water (western) region and gulls occur more frequently in the warm water (eastern) region?

3) Do seabirds occur more frequently near the frontal region of the Strait of Belle Isle?

4) Do wind conditions influence marine bird occurrences in the Strait, as has been reported in previous coastal studies?

Materials and Methods

i) Study area

The Strait of Belle Isle (Figure 1), with a mean depth of about 70 m and a variable width from about 17.4-34.7 km along its 100 km length (Toulany *et al.* 1987), is a narrow marine waterway separating the island of Newfoundland from mainland Canada. It has historically and traditionally been a region of interest because it provides a direct flow into the Gulf of St. Lawrence for water, ice and marine organisms carried southward by the Labrador Current. In counterpart, water mass with its own biological characteristics is expelled from the Gulf through the Labrador Sea. The Strait also acts as a passageway for the seasonal migration of regionally significant numbers of marine birds, mammals, salmon and other marine animals (Montevecchi and Tuck 1987), and is important as a major shipping route into and out of the Gulf of St. Lawrence.

The idea of steady flow through the Strait of Belle Isle may have been presented first by Bayfield (1837; as described by Garrett and Toulany (1981)) after observations of ice drift through the Strait. Pioneering studies of the oceanography of the Strait date back to 1894, when Dawson's (1907, 1913) summertime current measurements showed that the flow was characterized by reversing tidal streams and low frequency residual flows (Garrett and Toulany 1981). Huntsman *et al.* (1957) described biological evidence for Labrador Current flow into the Gulf of St. Lawrence. Current measurements and hydrographic data also provided some evidence for net inflow from the Labrador Sea into the Gulf of St. Lawrence at the northwestern end of the Strait and outflow from the Gulf into the Labrador Sea at the southeastern end. Farquharson and Bailey (1966) concluded from current, sea level and meteorological data that sea level difference across the Strait (directly influenced by atmospheric pressure gradients across the Strait) correlates well with magnitude and direction of daily

mean surface and subsurface flows through the Strait. During a predominant outgoing flow, the incoming flow is limited to a narrow band of water from the Labrador Current, which stays close to the western shore. During a predominant incoming flow, the incoming water covers a much wider area and includes some of the less cold water from the offshore part of the Labrador Current. Thus, horizontal temperature gradients are usually stronger for a well-established outgoing flow than for an incoming flow. More recent research (Garrett and Petrie 1981, Garrett and Toulany 1981, 1982) support these findings.

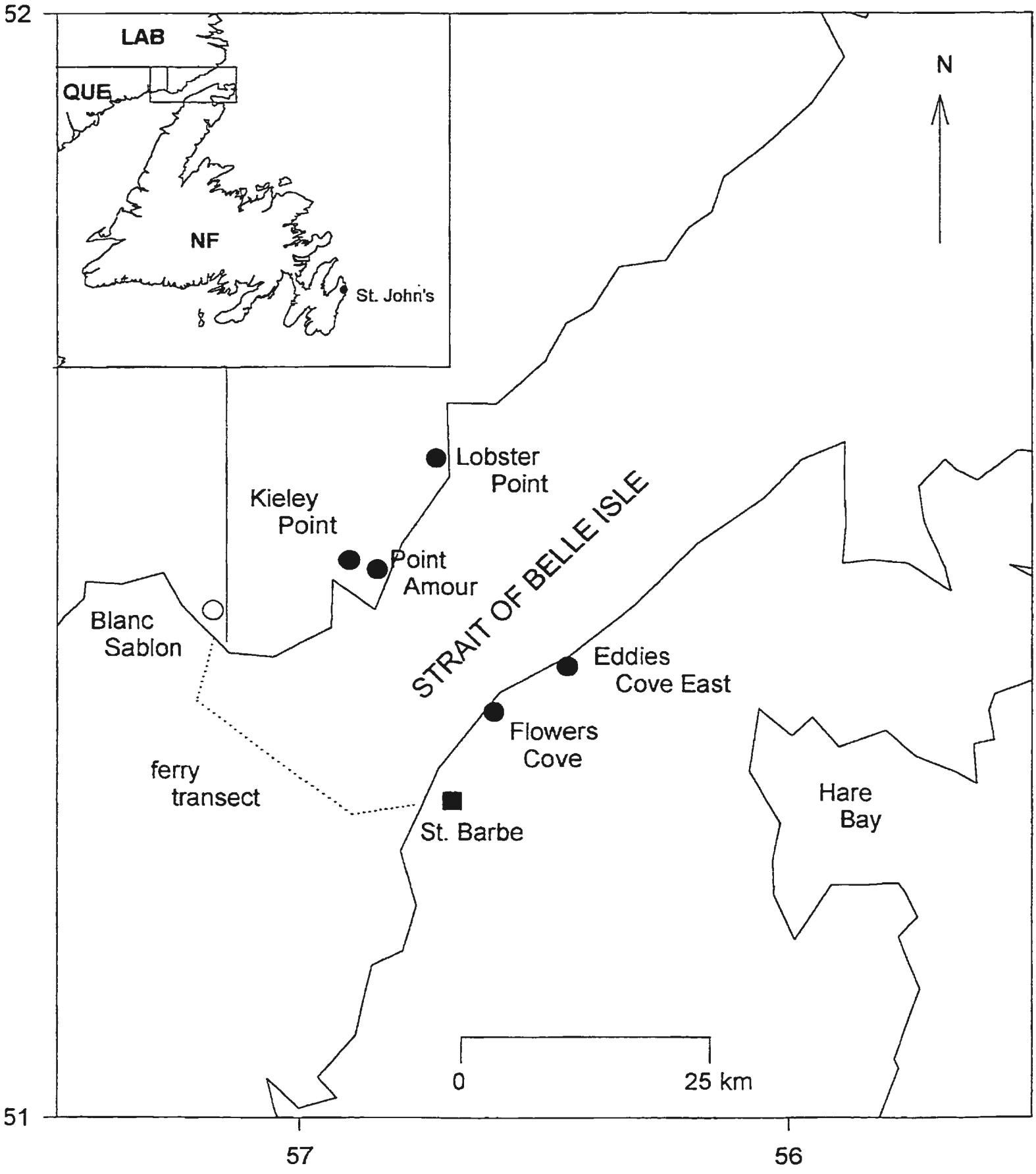
Pressure gradients responsible for flow through the Strait probably act by causing wind-driven rises in sea level in the northeastern Gulf of St. Lawrence or decreases in sea level on the Labrador Shelf (Garrett and Toulany 1981, 1982). Toulany *et al.* (1987) provides evidence that the along-strait barotropic pressure gradient is the major factor driving the currents through the Strait of Belle Isle.

Flow through the Strait of Belle Isle is highly variable on small and large temporal scales, with periods of dominant flow in either direction (Farquharson and Bailey 1966; Rose and Leggett 1988). Montevecchi (1996) reports a net inflow of cold, less saline water from the Labrador Current and a net outflow of warm, saline water from the Gulf of St. Lawrence. The cold water tends to remain along the west coast while the warm water remains along the east coast.

The Strait of Belle Isle is a region of relatively low primary productivity. The western shore of the Strait exhibits low average levels of primary production (Rose and Leggett 1988). Dickie and Trites (1983) describe the Strait as a biological "desert". Low nutrient concentrations, low algal biomass, and the lowest levels of primary production recorded in the Gulf of St. Lawrence have been reported by Steven (1974; described by Montevecchi 1996). However, Rose and Leggett (1988) describe periodic levels of high primary production, unusually cold coastal waters and rapid declines

in surface temperature (up to 10°C over 10 days) along the northeastern shore of the Gulf of St. Lawrence during summer as evidence of periodic coastal upwelling. Lauzier *et al.* (1957) hypothesized that nearshore cold surface waters were a result of offshore (NW) wind forced upwelling. Lavoie *et al.* (1986; described by Rose and Leggett 1988) used satellite images of sea surface temperatures to confirm periodic occurrence of bands of cold coastal water and suggested that coastal upwelling resulted from alongshore wind-driven Ekman transport. Oceanographic data obtained by Rose and Leggett (1988) confirmed the alongshore wind-driven upwelling hypothesis.

Figure 1. Map of Strait of Belle Isle, showing ferry terminal (■), ferry transect route (---), land count points (●) and wind recording station (○).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ii) Bird counts

Data collection

Counts of seabirds were made across the Strait of Belle Isle in order to test the hypotheses that birds may favor a frontal region or one water mass. Land-based counts were also made from each side of the Strait to further assess the hypothesis that different seabird communities may exist on different sides of the Strait. Seabird counts were made from the CN ferry *Northern Princess* during trips between St. Barbe, Newfoundland, and Blanc Sablon, Quebec during May 28-30, July 3-5, August 1-5, September 2-6 and November 8-10, 1996 across the Strait of Belle Isle (Table 1; Figure 1). Counts were also made from six land points along the Strait of Belle Isle during May 29-30, July 2-5, August 2-5, September 3-6, and November 8-11(Table 2; Figure 1). Shipboard counts were taken from the bridge and deck of the *Northern Princess*, 10 m above sea level, using a 90° 300 m port beam-to-bow strip-transect method (Tasker *et al.* 1984). The ferry's mean speed during the transects varied from 9.5-12.6 knots. Counts began as soon as the ferry left dock and lasted until the ferry reached port, whenever conditions permitted. A member of the *Northern Princess* crew recorded the ferry's position from a shipboard GPS monitor every 15 min during the counts. Sea-surface temperature (SST) was recorded every 10 s using a Vemco Minilog temperature probe which was towed along the surface during each transect, approximately 20-30 m behind the ferry. For land-based counts, all birds crossing a 500 m line perpendicular to the coast were recorded continuously for up to 4h (Table 1).

For both the land-based and ship-based counts, all seabirds and marine mammals visible by eye were identified to the lowest taxon and the number of individuals, distance from the observer, behaviour (e.g. flying, on water, diving), direction (for flying birds), and age classifications (adults,

sub-adults, birds of the year) were recorded. A pair of 10 x 50 binoculars was used to assist in identification, whenever necessary. Times of sightings were recorded in Newfoundland Standard Time (NST) to the nearest minute. Other notes (e.g. birds following fishing boats) were recorded as necessary. During ship-based transects, an effort was made to count ship-following birds only once. At the start and finish of each counting period, wind speed and direction, air temperature, visibility, % cloud cover, % ice cover, wave height and precipitation were recorded. Any substantial changes in environmental conditions occurring during the counting periods were recorded.

Continuous land-based counts were provided by the Canadian Wildlife Service to quantify the correlations of seabirds with wind patterns across the Strait. These counts were conducted from Point Amour, Labrador (Figure 1) by B. MacTavish, J. Selno, J. Wells and S. Gilliland, using the same method, from dawn to dusk every day from April 19 to May 25, 1996. A spotting scope was used to assist in species identification.

S. Porter of Environment Canada provided hourly measurements of wind speed and direction from April to November 1996. Measurements were made from the airport in Blanc Sablon, Labrador (Figure 1). The long-shore components of these data were calculated using a 45° angle clockwise from North and were used with the land counts provided by the Canadian Wildlife Service to analyze the influence of the wind patterns on seabird distributions.

Table 1. Dates, starting locations, start times, and durations of transects of the Strait of Belle Isle made on the *Northern Princess* during May, July, August, September and November 1996. Observations were made by K. LeGrow and W. Montevecchi.

Date	Start Location	Transect	Start Time (NST)	Duration (min)
May 28	St. Barbe	1	1042	65
May 28	Blanc Sablon	2	1301	77
May 28	St. Barbe	3	1521	66
May 30	Blanc Sablon	4	0931	33
May 30	St. Barbe	5	1042	82
May 30	Blanc Sablon	6	1255	85
May Total				**408**
July 3	Blanc Sablon	7	1659	93
July 4	St. Barbe	8	0828	64
July 4	Blanc Sablon	9	1045	80
July 4	St. Barbe	10	1318	60
July 4	Blanc Sablon	11	1505	78
July 5	St. Barbe	12	1217	74
July 5	Blanc Sablon	13	1438	82
July Total				**531**
Aug 1	St. Barbe	14	1242	99
Aug 1	Blanc Sablon	15	1458	107
Aug 2	St. Barbe	16	1158	59
Aug 3	St. Barbe	17	1246	89
Aug 3	Blanc Sablon	18	1515	103
Aug 3	St. Barbe	19	1725	101
Aug 5	Blanc Sablon	20	0801	102
Aug Total				**660**
Sept 2	St. Barbe	21	1020	102
Sept 2	Blanc Sablon	22	1233	105
Sept 3	St. Barbe	23	1020	103
Sept 3	Blanc Sablon	24	1242	105
Sept 3	St. Barbe	25	1503	102
Sept 5	Blanc Sablon	26	0802	108
Sept 5	St. Barbe	27	1023	108
Sept 5	Blanc Sablon	28	1237	108
Sept 6	St. Barbe	29	1157	105
Sept 6	Blanc Sablon	30	1402	107
Sept Total				**1053**
Nov 8	St. Barbe	31	1040	99
Nov 8	Blanc Sablon	32	1255	103
Nov 8	St. Barbe	33	1508	129
Nov 9	Blanc Sablon	34	0802	120
Nov 9	St. Barbe	35	1033	120
Nov 10	Blanc Sablon	36	1240	107
Nov Total				**678**
Total (min)				**3330**

Table 2 . Dates, locations, start times, and durations of counts made from land during May, July, August, September and November 1996. Observations were made by K. LeGrow and W. Montevecchi.

Date	Location	Start Time (NST)	Duration (min)
May 29	Kieley Point	0615	240
May 29	Lobster Point	1300	120
May 29	Kieley Point	1600	240
May 30	Eddies Cove East	1532	180
May Total			**780**
July 2	Eddies Cove East	0955	240
July 3	Point Amour	0825	240
July 4	Eddies Cove East	1050	240
July 5	Flowers Cove	0627	180
July Total			**900**
Aug 2	Flowers Cove	0630	240
Aug 3	Flowers Cove	0613	240
Aug 5	Eddies Cove East	1030	240
Aug Total			**720**
Sept 3	Flowers Cove	0622	188
Sept 4	Point Amour	0620	240
Sept 6	Eddies Cove East	0633	240
Sept Total			**668**
Nov 8	Flowers Cove	0741	117
Nov 9	Point Amour	1420	147
Nov 10	Point Amour	0913	137
Nov 11	Eddies Cove East	0750	180
Nov Total			**581**
Total (min)			**3649**

Data analysis

Ferry transects were approximately 35.5 km long and were divided into 18 segments of equal length, each measuring approximately 1.97 km. This division is appropriate because it provides a suitable scale at which to detect a front. Mean sea surface temperature (SST) values were calculated for each segment by calculating the mean of all SST values collected during the segment. Mean standardized seabird counts were calculated for each of these segments. Since the time taken to complete the transects (and the segments) varied during the study period, counts were initially standardized per minute for each segment individually, according to the following calculation:

$$\frac{\text{\# birds counted in the segment}}{\text{Time taken to complete the segment}} = \frac{\text{\# birds}}{\text{segment·minute}}$$

This value was standardized per 5 min effort to give the standardized count:

$$\text{Standardized count} = \frac{\text{\# birds}}{\text{segment·5 minutes}}$$

The mean standardized count was calculated for each region of the Strait (east/west or frontal/non-frontal) according to the following calculation:

$$\text{Mean standardized count} = \frac{\Sigma \text{ standardized counts in the region}}{\text{Number of segments in the region}}$$

The mean standardized counts were used in all GLM tests.

Pair-wise differences (d) in SST were calculated within the 18 consecutive mean SST measurements along each transect ($d_i = (SST_{i+1}-SST_i)$, i = 1-17). The greatest difference was identified in each transect. For the water mass and frontal analyses, the Strait was divided into two regions based on this maximum difference: east/west or frontal/non-frontal. The border between the east/west regions was defined as the border between the two transect segments having the greatest difference in SST. The front was defined as the six transect segments adjacent to this border (three

on each side). The remaining transect segments on each side of the front were pooled to form the "non-frontal" region. Thus, for each transect, the front and the east/west regions are centered on the same point - the border between the two transect segments having the greatest horizontal SST gradient between them.

Due to ship-board trouble with the temperature probe, SST measurements were not obtained for the ferry transects during the months of May, July and August. The ferry engineer recorded temperatures of water inflow into the engine cooling system; these values were higher than SST values but SST changes across the Strait were still detectable and corresponded well with the changes in SST values measured from the probe (when compared). Thus, these values were used to detect the locations of the front and the east/west water mass border during May, July and August. The locations of the front (and east/west border) were plotted on a graph to examine how the front and border behaved over the study period.

The Percent Similarity Index (PSI) was calculated as a measure of similarity in the seabird communities between eastern and western regions. PSI was calculated according to the formula:

$PSI = \Sigma Min(P_{East}, P_{west})$, where:

P_{east} = the percentage of species i occurring in the eastern region

P_{west} = the percentage of species i occurring in the western region

i = 1 to n, n = the total number of species observed between the eastern and western regions

All identified seabird species were used in the PSI calculation (Appendix 3).

Because of the uncertain identification of some species (e.g. unidentified alcids, unidentified gulls; Appendix 1) data analysis was carried out using the most taxonomic groups: *Uria* spp., *Larus* spp., members of the Family Alcidae and of the Family Laridae. General Linear Models (GLMs) were

carried out on the ferry data for each of the most common species, first on genera and then on families, using transect and region of the Strait as explanatory variables to determine whether mean counts differed significantly between transects and regions of the Strait. For each test of counts from eastern and western regions of the Strait, the following pair of hypotheses was tested:

H_o: $\mu_{east} = \mu_{west}$ vs. H_a: $\mu_{east} \neq \mu_{west}$

For each test of counts from frontal and non-frontal regions, the following pair of hypotheses was tested:

H_o: $\mu_{front} = \mu_{non\text{-}front}$ vs. H_a: $\mu_{front} > \mu_{non\text{-}front}$

Due to the large number of statistical tests being run on the data, a significance level of $\alpha = 0.05$ was not suitable. The Bonferroni method is a conservative strategy used in order to lower the probability of making a Type I error in the entire set of statistical tests run on the data set. This new critical value, α", is calculated by $\alpha" = \alpha/k$, where k = the total number of statistical tests being run for the entire study (Sokal and Rohlf 1995) and α is set at the standard value of 0.05. There are 4 planned GLM tests for each set of data analysis, so the critical significance value for each data analysis is $\alpha" = 0.05/4 = 0.0125$.

The power of each test for which the null hypothesis was not rejected was examined in order to determine how much bigger the difference between the means would have to be (at the observed level of variance) to be significantly different (at α"). This examination was performed by increasing the greater of the two observed mean counts being tested (for the east/west data analysis) or by increasing the mean count at the frontal region (for the frontal/non-frontal data analysis, consistent with H_a) in 10 % increments and re-executing the test until $p < \alpha$". The power of these tests was also examined by calculating how many transects would have to be run (i.e. how large n would have

to be) in order to detect a significant difference in counts between the pairs of regions being examined (east/west or front/non-front) at the observed level of variance. This was executed by fixing the observed value of the F-statistic for each test (i.e. fixing the level of variance) and increasing the degrees of freedom of the denominator until the p-value was lower than α". This minimum n was calculated using $n = d+2$, where d = critical degrees of freedom of the denominator of the F-statistic.

Daily means of the land-based counts provided by the Canadian Wildlife Service Land were divided into four taxonomic groups: alcids, gulls, ducks (scoters, *Melanitta* spp. and Common Eiders, *Somateria mollissima*) and Common Loons (*Gavia immer*). Autocorrelation analyses of the daily means were performed on each species group, at lags increasing from 0 to 10 days. The lag at which the autocorrelation coefficients equal zero indicates the lag required to obtain independent counts, which are desirable to overcome integrated effects of previous wind events. Cross-correlation analyses were performed on daily longshore wind component means and daily means of each of the four taxonomic groups of marine birds. Cross-correlations were calculated at a lag favoring the birds, i.e. winds recorded at day t are correlated with bird counts at day t+k, where k varied from 0 to 10 days.

All statistical analysis was carried out using Minitab for Windows.

Results

i) Abundances of marine birds observed in the Strait of Belle Isle

A total of 11 498 individual seabirds from 29 taxonomic groups (including 21 positively identified species) were observed during 3330 min of observation from the *Northern Princess* and 9604 individual seabirds from 51 taxonomic groups (including 31 positively identified species) were observed during 3649 min of observation from 5 land points between May and November 1996 (Figure 1; Tables 1-2; Appendices 1-3). Nine of the taxonomic groups (including 5 of the identified species) were observed only during ferry transects, 28 of the groups (including 18 species) were observed only during land transects, and 24 of the groups (including 12 species) were observed during both ferry and land transects (Appendix 1).

Data analyses are based on taxonomic groupings because no single species was either abundant enough or reliably identified enough to justify individual analysis. Gulls and alcids were the two most common groups of birds observed during ferry transects. Gulls, representing 4 of the positively identified species (Appendix 1) and 2 of the taxonomic groups, represented 77 % of all birds seen during ferry transects. Alcids, representing 4 positively identified species (Appendix 1) and 2 taxonomic groups, represented 16 % of all individual birds. Collectively, alcids and gulls represented 92 % of all the seabirds observed during this study and also represent the main ecological groupings of seabirds: pursuit divers (alcids) and surface foragers (gulls). Analysis of the ferry transect data was based on 4 taxonomic groups: *Uria* species, *Larus* species and members of the families Alcidae and Laridae. The family classifications are cumulative (i.e. they consist of all observed birds which belong to the families, including the previously described *Uria* and *Larus* species; Figure 2). Heterogeneity in behavioural responses within the taxonomic classifications used

in this study is likely minimal because of the ecological similarity of the species included in each group: pursuit-diving alcids and generalist, surface feeding gulls.

The taxonomic breakdown of the land-based transects was not as distinct. The most common taxonomic group observed from land was unidentified *Larus* species, comprising 25 % of all birds seen from land. The next most frequent groups were Herring Gulls *(Larus argentatus)* comprising 15 %, Great Black-back Gulls *(Larus marinus)*, 13 % and Common Eiders (*Somaterria mollissima*), 13 %. Neither of the 40 remaining taxonomic groups represented more than 5 % of the total counts during land transects (Appendix 2).

ii) Distribution and abundance patterns of marine birds the Strait of Belle Isle in relation to water masses

The mean ferry-based counts of each taxonomic group in east and west regions of the Strait from ferry transects are presented in Table 3. The Percent Similarity Index between these two regions is 0.651 or 65 %. General Linear Model (GLM) tests using transect and region of Strait (east or west) as explanatory variables were also carried out on counts of the four taxonomic groups at the eastern and western sides of all ferry-based transects. This test was used to determine whether transect and region were independent explanatory variables and to determine which taxonomic groups resulted in significantly different counts between eastern and western regions of the Strait. The interaction term (region*transect) in each test was considered first. The interaction terms of all these tests are given in Table 4. A significant interaction term for a GLM test indicated that differences in counts between eastern and western regions were not independent of transect and thus differences between regions were not consistent across transects. If interaction was significant, further one-way

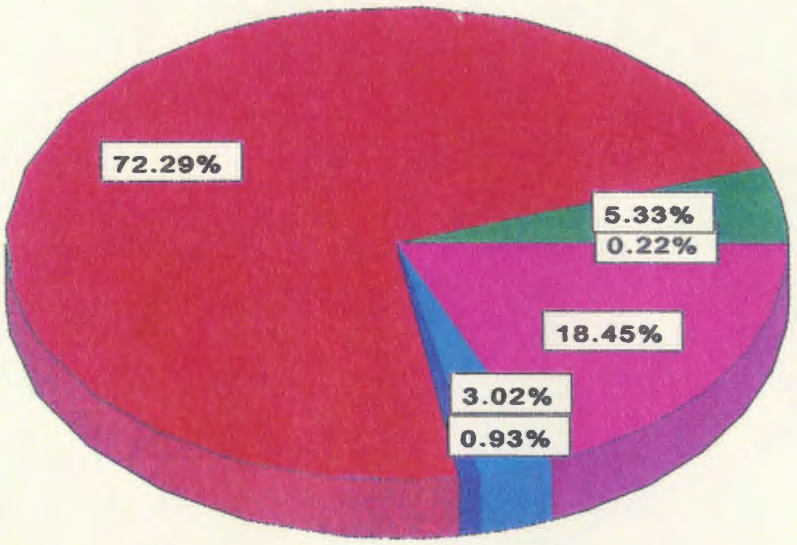
Analysis of Variance (ANOVA) tests were executed on the counts at the eastern and western sides of each transect.

The interaction term was significant for the GLM tests involving counts of *Uria* spp., *Larus* spp., Alcidae and Laridae (Table 4). One-way ANOVA tests were carried out on all counts of these groups at each individual transect. Only counts of *Larus* spp. in transect 11 ($p = 0.011$) and of Laridae in transect 20 ($p = 0.012$) resulted in significant differences between east and west regions, at $\alpha = 0.05$ with Bonferroni correction ($\alpha" = 0.0125$).

The results of the first statistical power examination of the GLM tests (i.e. required increases in mean counts) are given in Table 6. Required percentage increases in means to achieve significant differences ranged from 2 % to 563 % (Table 6).

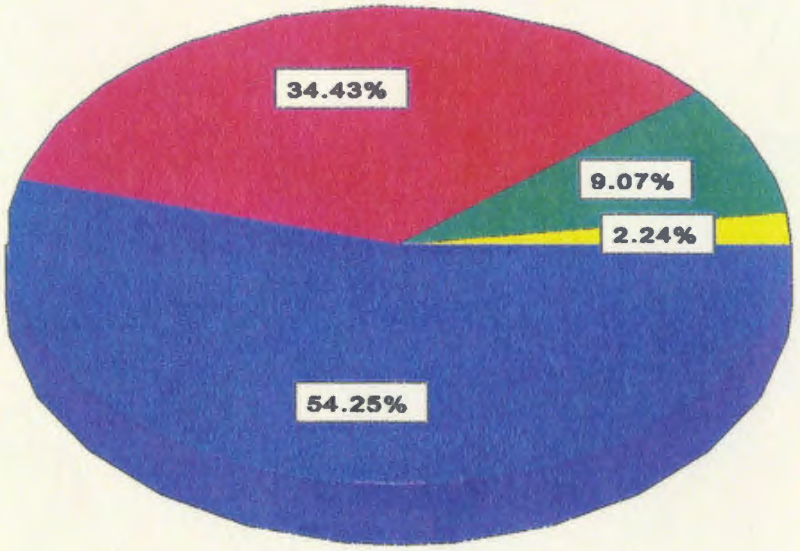
Power analysis was performed by examining the size of n in each case (i.e. calculating how large n would have to be) in order to obtain a statistically significant result for each statistical test. This examination of the critical size of n indicated that for all taxonomic groups which did not show significant differences between eastern and western regions (either as a GLM or ANOVA test), enough transects could not be run in a season in order to detect a significant difference between eastern and western regions at the observed level of variance. The degrees of freedom of the denominator of each F-statistic from all of the GLM and ANOVA tests were raised as high as $n=10^6$ without resulting in a significant p-value.

Figure 2. Taxonomic breakdown of the [A] Alcidae and [B] Laridae classifications observed during the ferry transects. For full lists of all positively identified alcid and gull species, see Appendix 1.



Alca torda
Uria spp.
Fratercula arctica
Uria aalge
Cepphus grylle
Alcidae

[A]



Larus marinus
Rissa tridactyla
Larus argentatus
Larus spp.

[B]

Table 3. F-statistics and p-values for interaction terms of GLM tests on mean standardized counts (shown ±1 s.d.) of *Uria* spp., *Larus* spp., Alcidae and Laridae counts, in eastern and western water masses over 36 transects across the Strait of Belle Isle (F_{df}=35, 576 for all 4 tests. Sample size n=487 for all east counts and n=161 for all west counts). Median=0 for all counts. Bold p-values indicate statistically significant interaction terms at α=0.05 with Bonferroni correction (α"=0.0125).

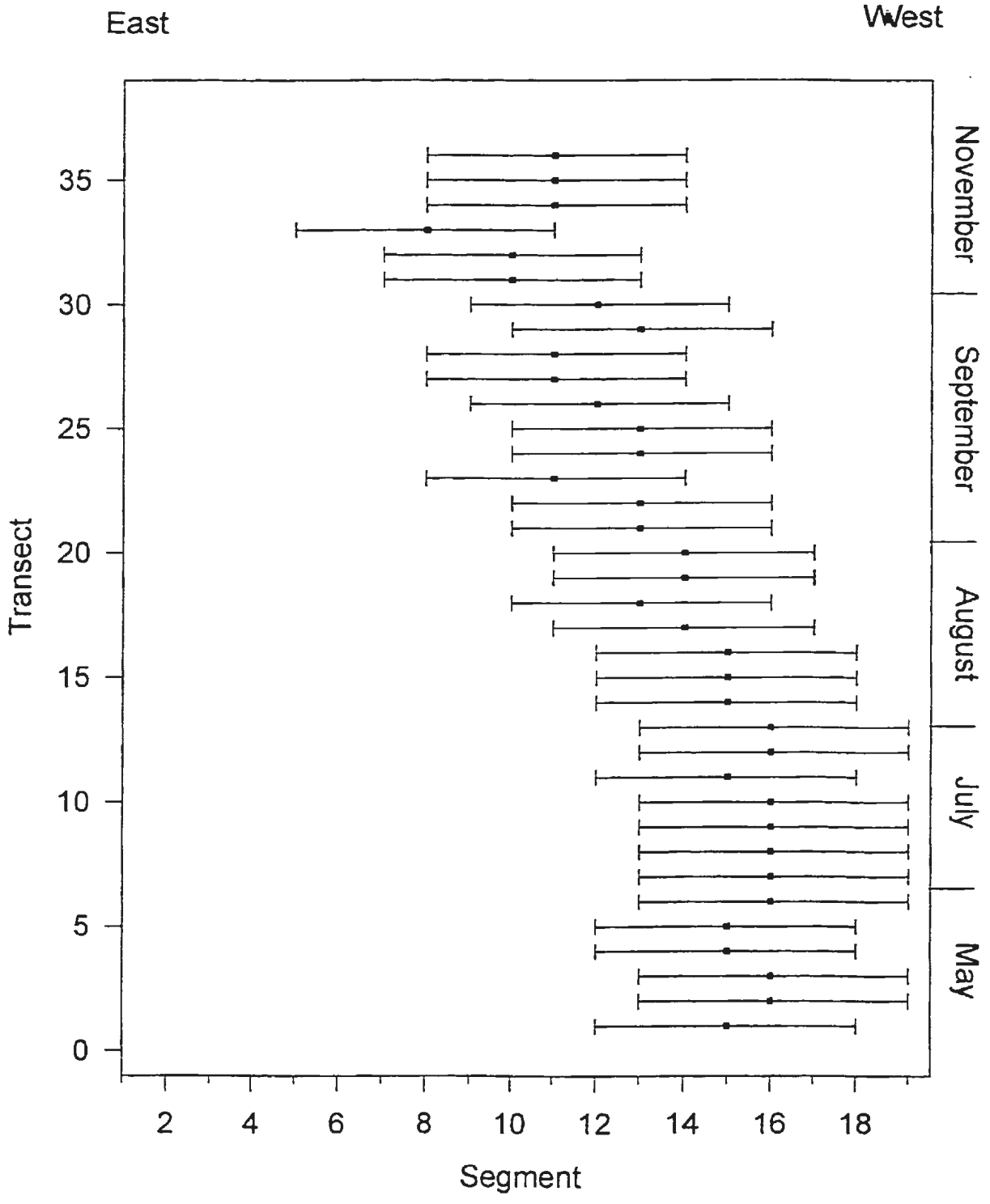
Taxonomic Group	Mean Standardized Count (birds/5 min) ± 1 s.d.		F-statistic of interaction term	P-value
	East	West		
Uria spp.	2.92 ± 12.04	0.51 ± 4.49	1.91	**0.002**
Larus spp.	0.93 ± 3.93	2.32 ± 9.35	4.20	**<0.001**
Alcidae	3.60 ± 13.66	0.91 ± 5.31	2.19	**<0.001**
Laridae	4.27 ± 23.80	13.98 ± 95.21	2.13	**<0.001**

iii) Relationships between distribution patterns of marine birds and mammals and frontal strength in the Strait of Belle Isle

Frontal occurrence during the study period is presented in Figure 3. The front tended to move eastward over the summer. The mean counts of the taxonomic groups in the frontal and non-frontal regions of the Strait across all 36 transects are presented in Table 5. General Linear Model (GLM) tests using transect and region of the Strait (frontal or non-frontal) as explanatory variables were carried out on counts of the four taxonomic groups from all ferry-based transects. This test was used to determine whether transect and region have independent effects on density and to determine which taxonomic groups showed significantly different counts between frontal and non-frontal regions of the Strait. The interaction term (region*transect) is considered first (Table 5). A significant interaction term for a GLM test indicates that differences in counts between frontal and non-frontal regions are not independent of transect and thus differences are not consistent across transects. Consequently, further one-way Analysis of Variance (ANOVA) tests must be executed on the counts at the frontal and non-frontal regions for each transect in order to determine which of the transects comprise significantly different counts between regions. The interaction term was not significant for the GLM tests involving counts of any of the four taxonomic groups (Table 6). Thus, single-way ANOVA tests were not necessary. The GLM tests indicated that there were no significant differences between mean counts at frontal and non-frontal regions for any of the taxonomic groups examined (Table 5).

The results of the first statistical power examination of the GLM tests (i.e. required increases in mean counts) are given in Table 5. Required percentage increases in means to attain significant

Figure 3. Distribution of frontal occurrence in each transect during this study. Symbols at the center of each line indicate points of maximum horizontal SST gradient and the bars represent the region around this point, defined as the front.


East
West
Transect
0
5
10
15
20
25
30
35
2
4
6
8
10
12
14
16
18
Segment
May
July
August
September
November

differences range from 61 % to 611 % (Table 7). Examination of the statistical power of the tests indicated that for all taxonomic groups, enough transects could not be run in a season in order to detect a significant difference between eastern and western regions at the observed level of variance. The degrees of freedom of the denominator of each F-statistic of the ANOVA tests were raised as high as $n=10^6$ without resulting in a significant p-value.

Table 4. F-statistics and p-values for interaction terms of GLM tests on mean standardized counts (shown ±1 s.d.) of *Uria* spp., *Larus* spp., Alcidae and Laridae counts, in frontal and non-frontal regions over 36 transects across the Strait of Belle Isle (F_{df}=35, 576 for all 4 tests. Sample size n=216 for all east counts and n=432 for all west counts). Median=0 for all counts. Bold p-values indicate statistically significant interaction terms at α=0.05 with Bonferroni correction (α"=0.0125).

Taxonomic Group	Mean Standardized Count (birds/5 min) ± 1 s.d.		F-statistic of interaction term	P-value
	Frontal	Non-frontal		
Uria spp.	2.22 ± 10.19	2.07 ± 10.27	0.54	0.987
Larus spp.	0.94 ± 3.22	1.61 ± 7.36	1.59	0.018
Alcidae	3.03 ± 12.94	2.55 ± 10.94	0.92	0.595
Laridae	3.11 ± 16.21	9.69 ± 70.39	0.61	0.964

Table 5. F-statistics and p-values from GLM tests run on counts of seabirds from four taxonomic groups at frontal and non-frontal regions during 36 transects across the Strait of Belle Isle and required increases in mean standardized counts (birds/5 min and %) for significant differences between these regions at α=0.05 with Bonferroni correction (α"=0.0125).

Taxonomic Group	F statistic	P-Value	Required Increase (birds/5 min)	Required Increase (%)
Uria spp.	0.04	0.847	1.70	77
Larus spp.	1.90	0.168	1.85	196
Alcidae	0.35	0.557	1.55	61
Laridae	1.80	0.180	19.0	611

iv) Responses of marine birds to variations in wind patterns in the Strait of Belle Isle

Autocorrelation and Cross-Correlation analysis

The r^2 values for alcid and gull counts equaled zero at a lag of 4-5 days, for loons at a lag of 3-4 days and for ducks at a lag of 6-7 days (Figure 4).

Maximum r^2 values occurred for alcids at a lag of 4 days and for gulls, for Common Loons and for ducks at a lag of 0 days. Alcids show positive correlation with the wind, all other taxonomic groups correlate negatively with the wind (Figure 5).

Figure 4. Distribution of the r^2 values of the autocorrelation functions of (A) alcids, (B) gulls, (C) Common Loons and (D) ducks observed from land in the Strait of Belle Isle at lags of 1-10 days.

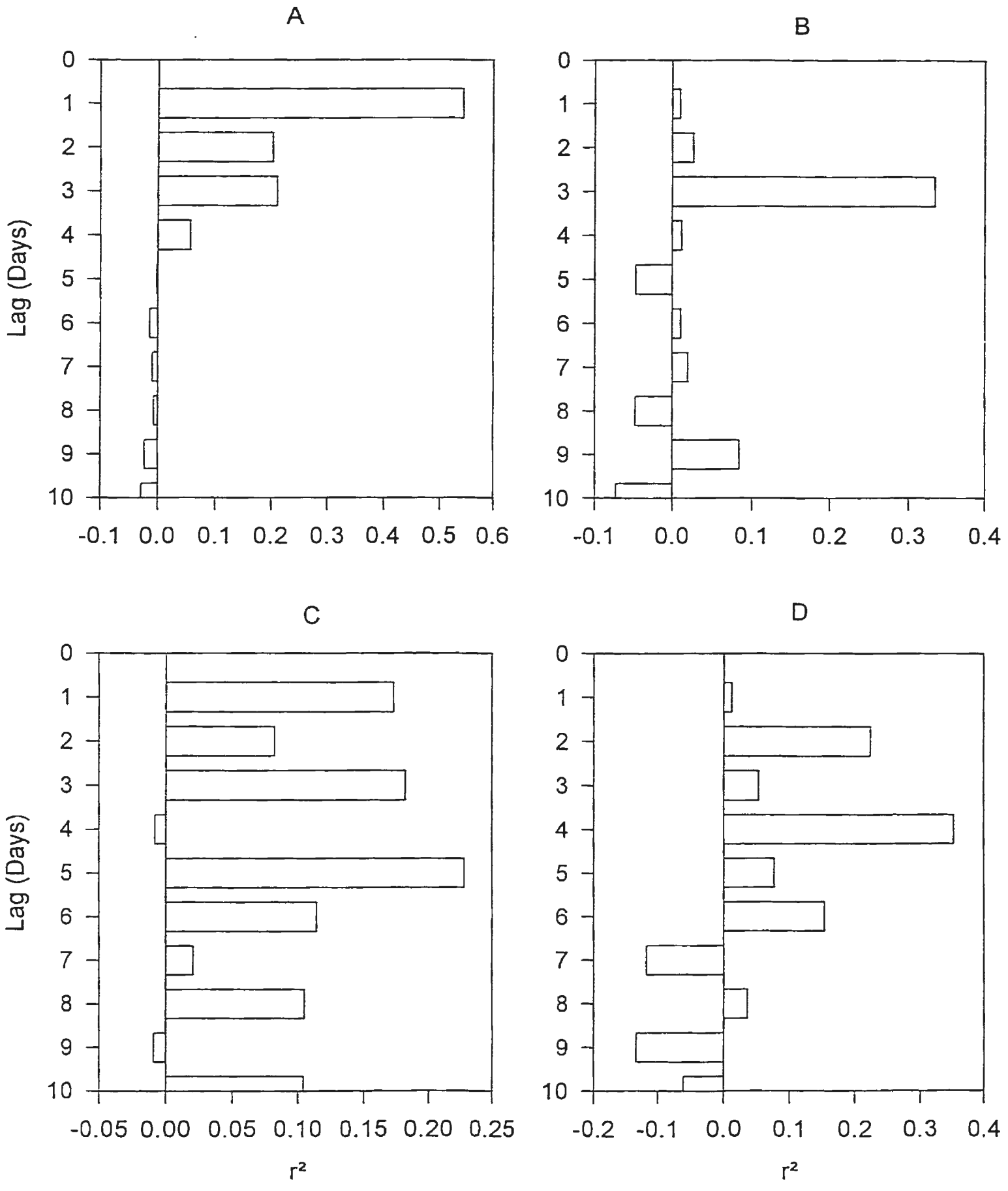
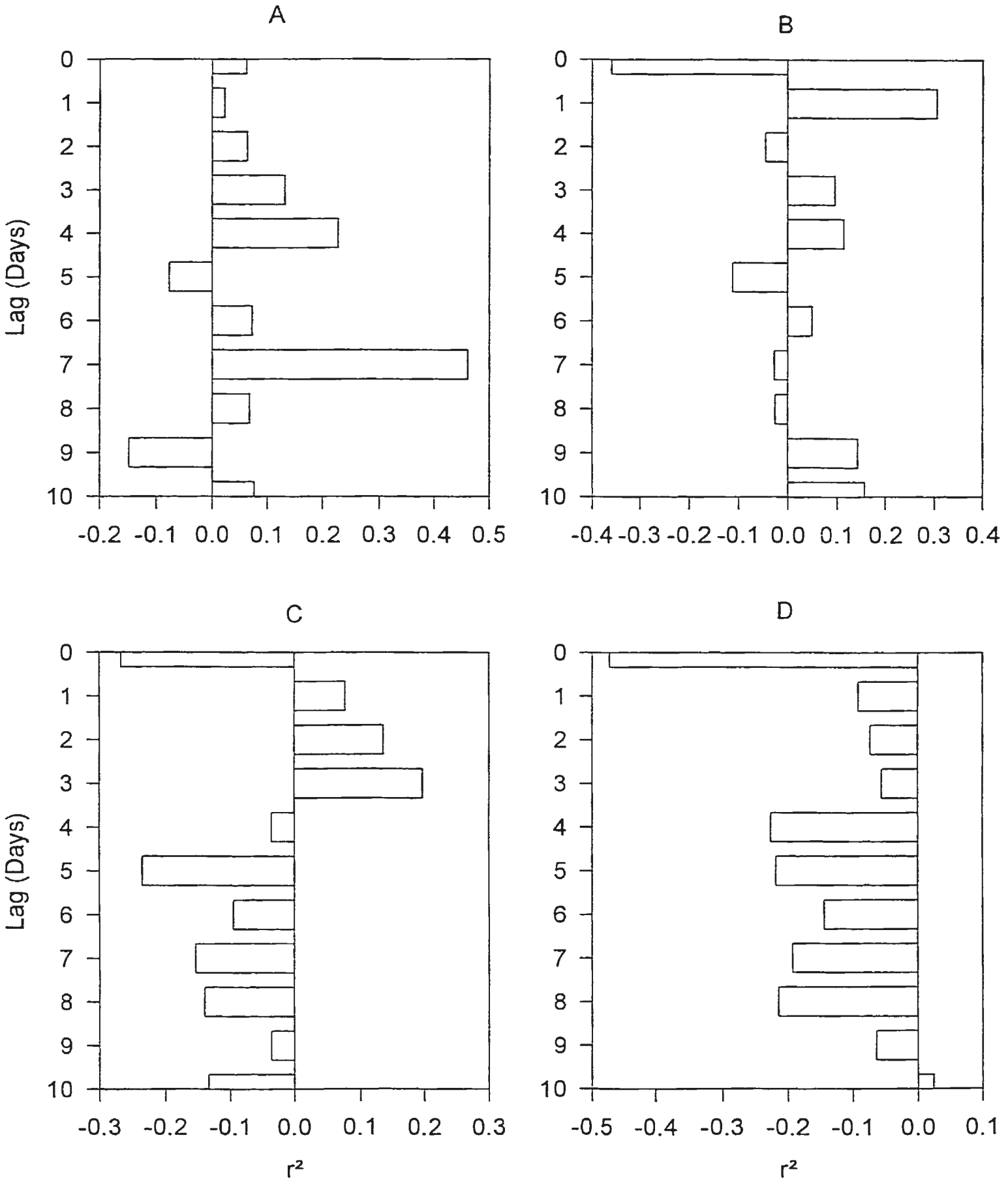

A
B
C
D
Lag (Days)
0
1
2
3
4
5
6
7
8
9
10
-0.1 0.0 0.1 0.2 0.3 0.4 0.5 0.6
-0.1 0.0 0.1 0.2 0.3 0.4
-0.05 0.00 0.05 0.10 0.15 0.20 0.25
-0.2 -0.1 0.0 0.1 0.2 0.3 0.4
r²

Figure 5. Distribution of the r^2 values of the cross-correlation functions of (A) alcids, (B) gulls, (C) Common Loons and (D) ducks observed from land in the Strait of Belle Isle and longshore wind measurements at lags of 1-10 days.


A
B
C
D
Lag (Days)
Lag (Days)
0
1
2
3
4
5
6
7
8
9
10
-0.2 -0.1 0.0 0.1 0.2 0.3 0.4 0.5
-0.4 -0.3 -0.2 -0.1 0.0 0.1 0.2 0.3 0.4
-0.3 -0.2 -0.1 0.0 0.1 0.2 0.3
-0.5 -0.4 -0.3 -0.2 -0.1 0.0 0.1
r²
r²

Discussion

On average, gulls and alcids did not occur more frequently at frontal regions than non-frontal regions in the Strait of Belle Isle. Rees (1963) reported that seabirds, particularly alcids, occurred more frequently at the frontal region of the Strait where the Labrador Current and Gulf Current water masses meet. However, this conclusion was based on relative comparisons of observations to bird counts from other parts of the Strait - no counts were presented or statistics used to strengthen these observations.

In the present study, there were no overall significant differences between eastern and western regions; only 2 of 36 transects showed significantly different mean counts between eastern and western water masses. Both times, the counts were of gulls. The Percent Similarity Index value indicates a 65 % overlap in abundance between these regions. Overlap greater than 50% indicates reasonably similar communities and strengthens the findings that these communities are, on average, not different, particularly for alcids.

The western side of the front may be episodically more productive than the eastern side due to coastal upwelling, implying that the western water mass may support more birds. Rees (1963) observed that Thick-billed Murres occurred more frequently on the western side but did not report the effort used in the study. The current observation that the mean counts of alcids and gulls over the two water masses were not significantly different implies that at the temporal scale considered in this study, these marine birds display no preference for either region of the Strait. Alcid breeding areas exist along the Labrador and Quebec shores (Cairns *et al.* 1989), so alcids would be expected to occur more frequently along the western side of the Strait. However, mean alcid counts were overall no higher in the western region.

No significant differences in counts were observed between frontal and non-frontal areas, supporting the conclusions of Schneider *et al.* (1987) that episodic aggregations may occur but, on average, seabirds do not occur more frequently at fronts. However, a number of other studies (e.g. Begg and Reid 1997) have concluded that fronts support large aggregations of seabirds, acting as an important seasonal resource and consequently as an agent of high seabird species diversity. A front was clearly detected during each transect of this study, yet no significant aggregations were detected. This may be due in part to the spatial scale over which this study was conducted. This study was based on opportunistic ferry crossings on the Strait of Belle Isle and that because of the spatial restrictions involved, the conclusions reached are not necessarily general to the entire Strait. Future studies over larger spatial scales through the entire Strait would improve the chance of detecting a front and of measuring the extent of any association between seabirds and fronts.

Studies on the distributions of marine avifauna have to consider the spatial scales over which the studies are executed. Fronts usually occur over small spatial scales and marine birds are several trophic steps above phytoplankton and zooplankton (Schneider 1982). All of the increased primary production at fronts may not be conveyed through all tertiary levels of the food web (phytoplankton -> zooplankton -> birds or phytoplankton -> zooplankton -> fish -> birds) at the front. Thus, seabird aggregations may not directly reflect increased primary production levels at fronts.

Most of the differences in seabird abundance observed during this study between east and west or frontal and non-frontal regions would have to increase in order to display statistically significant results, some by as much as 600 % (Appendix 4; Table 5). Furthermore, at the observed level of variance, as many as 10^6 transects would not have revealed statistically significant differences in mean counts between east/west of frontal/non-frontal regions. Such a number of transects would

be practically and logistically impossible. This indicates that at the observed variance level, the required effort would be too huge to undertake.

The results suggest that alcid counts are independent at a lag of 1 day but counts of gulls, Common Loons and ducks are independent after lags of approximately 3, 4 and 5 days respectively (Figures 4-5). Thus, in considering future influences of wind events on seabird movements in the Strait of Belle Isle, counts should be made at the intervals indicated in order to overcome integrated effects of previous wind events.

The cross-correlation analysis seems to indicate that high wind events result in reduced movement of gulls, Common Loons and ducks at a lag of 0 days (Figure 5). Alcids show no correlation with wind events at a lag of 0 days (Figure 5). Decreased visibility on days of strong winds may explain this result for the gulls, Common Loons and ducks but not for the alcids. It would be expected that reduced visibility would affect alcid counts most severely, as alcids fly very close to the sea surface. If the wind events were solely responsible for increases in seabird movement, as may occur in a pelagic environment, cross-correlation between seabirds and wind events should be high and positive at 0 lag and slowly diminish as the lag increases and the wind subsequently decreases. The cross-correlation analysis indicates that this is not the case, suggesting that wind does not strongly influence seabird movements in the Strait of Belle Isle. Blomqvist and Peterz (1984) proposed that under high wind conditions, pelagic seabirds will tend to move along a wave trough until they meet the coast, when they will move against the wind along the coastline. If this is the case, then the cross-correlation should be low and negative at lag of 0 days (due to reduced visibility and movement) and high and positive at a lag of 1 day (as movement resumes after the wind diminishes). This trend was seen for the gulls and Common Loons but not for alcids or ducks (Figure 5).

Summary and Future Considerations

These results indicate that on average, alcids and gulls show no preference between eastern and western or between frontal and non-frontal regions in the Strait of Belle Isle. In relation to the initial hypotheses:

i) Alcids and gulls dominate the Strait of Belle Isle; 92 % of all seabirds observed during this study fell into one of these two classifications. No single species was either abundant enough or reliably identified enough to justify individual analysis. Thus, observed species of the genera *Uria* and *Larus* and of the families Alcidae and Laridae were analysed as taxonomic groups based on their abundance and ecological similarity.

ii) Neither alcids nor gulls displayed a preference for either water mass in the Strait of Belle Isle. Mean counts of gulls were consistently higher on the western side of the Strait and counts of alcids were higher on the eastern side, but none of the differences between regions were statistically significant.

iii) Neither alcids nor gulls displayed a preference for the frontal region of the Strait of Belle Isle. A prominent frontal region regularly occurred throughout the study and tended to move eastward from May to November.

iv) Counts of gulls, ducks and Common Loons tend to decrease immediately following strong wind events. Alcids were most active four days after strong wind events.

The power analysis of this study indicated that at the observed level of variance, it would be impossible to run enough transects to detect significant differences in seabird counts between frontal and non-frontal or between eastern and western water masses in the Strait of Belle Isle. Such analysis may be important in future studies of seabird distributions in the Strait of Belle Isle.

It is noteworthy that large increases in counts of Black-legged Kittiwakes and unidentified gulls, as well as virtually all counts of marine mammals, occurred in September (Appendix 2), representing 67% of all birds observed during this study. This count increase is disproportionately higher than the increase in effort in September (Table 1). This likely indicates an autumn migratory

movement of gulls, kittiwakes and marine mammals through the Strait of Belle Isle. Knowledge of such movements may be valuable to future studies.

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Appendix 1. Bird and mammal species observed and observation locations (ferry (F) and land (L)) during counts on the Strait of Belle Isle during May-November 1996.

Aves	
Gaviiformes	
Gaviidae	
Common Loon (*Gavia immer*)	F, L
Red-throated Loon (*Gavia stellata*)	L
Unidentified loon	L
Procellariiformes	
Procellariidae	
Northern Fulmar (*Fulmarus glacialis*)	F
Greater Shearwater (*Puffinus gravis*)	F
Sooty Shearwater (*Puffinus griseus*)	F
Unidentified shearwater	F
Hydrobatidae	
Unidentified storm petrel	F
Pelecaniformes	
Sulidae	
Northern Gannet (*Morus bassanus*)	F, L
Phalacorcoracidae	
Double-crested Cormorant (*Phalacrocorax auritus*)	L
Anseriformes	
Anatidae	
Unidentified duck	F, L
Anatinae	
Mallard (*Anas platyrhynchos*)	L
Aythyinae	
Common Eider (*Somateria mollissima*)	F, L
White-winged Scoter (*Melanitta deglandi*)	L
Surf Scoter (*Melanitta perspicillata*)	L
Black Scoter (*Melanitta nigra*)	F, L
Unidentified scoter	F, L
Unidentified eider	L
Unidentified diving duck	L

Appendix 1 (cont.)

Merginae	
Red-breasted Merganser (*Mergus serrator*)	L
Unidentified merganser	L
Falconiformes	
Accipitridae	
Accipitrinae	
Unidentified hawk	L
Pandionidae	
Osprey (*Pandion haliaetus*)	L
Charadriiformes	
Charadriidae	
Semipalmated Plover (*Charadrius semipalmatus*)	L
Unidentified plover (Charadriidae)	F, L
Scolopacidae	
Whimbrel (*Numenius phaeopus*)	L
Yellowlegs spp.(*Tringa* spp.)	L
Spotted Sandpiper (*Actitis macularia*)	L
Ruddy Turnstone (*Arenaria interpres*)	L
White-rumped Sandpiper (*Calidris fuscicollis*)	L
Unidentified sandpiper	F, L
Stercorariidae	
Unidentified jaeger	L
Laridae	
Larinae	
Glaucous Gull (*Larus hyperboreus*)	L
Iceland Gull (*Larus glaucoides*)	F, L
Greater Black-backed Gull (*Larus marinus*)	F, L
Herring Gull (*Larus argentatus*)	F, L
Ring-billed Gull (*Larus delawarensis*)	L
Black-legged Kittiwake (*Rissa tridactyla*)	F, L
Unidentified hooded gull	F
Unidentified gull	F, L

Appendix 1 (cont.)

Sterninae	
Common Tern (*Sterna hirundo*)	F
Arctic Tern (*Sterna paradisaea*)	L
Unidentified tern	F, L
Alcidae	
Razorbill (*Alca torda*)	F, L
Common Murre (*Uria aalge*)	F, L
Dovekie (*Alle alle*)	F
Black Guillemot (*Cepphus grylle*)	F, L
Atlantic Puffin (*Fratercula arctica*)	F, L
Unidentified alcid	F, L
Unidentified murre	F, L
Passeriformes	
Corvidae	
American Crow (*Corvus brachyrhynchos*)	F, L
Northern Raven (*Corvus corax*)	L
Mammalia	
Cetacea	
Unidentified whale	F, L
Mysticeti	
Balaenopteridae	
Fin Whale (*Balaenoptera physalus*)	F
Minke Whale (*Balaenoptera acutorostrata*)	F
Humpback Whale (*Megaptera novaeangliae*)	F
Odontoceti	
Delphinidae	
Killer Whale (*Orcinus orca*)	F
Unidentified dolphin	F, L
Pinnipedia	
Phocidae	
Unidentified seal	F

Appendix 2. List of all species and total numbers of individuals observed during ferry-based transects from May-November 1996.

	Month					
Species	May	July	August	September	November	**Total**
Common Loon (*Gavia immer*)	0	5	0	0	0	**5**
Northern Fulmar (*Fulmaris glacialis*)	0	39	30	23	122	**214**
Sooty Shearwater (*Puffinus griseus*)	0	6	14	123	0	**143**
Unidentified shearwaters (*P.* spp.)	0	0	0	3	0	**3**
Unidentified storm petrels	0	1	1	0	0	**2**
Northern Gannet (*Sula bassens*)	0	16	53	10	0	**79**
Common Eider (*Somateria mollissima*)	40	0	0	0	0	**40**
Black Scoter (*Melanitta nigra*)	0	11	0	2	0	**13**
Unidentified scoter (*Melanitta* spp.)	20	0	0	0	0	**20**
Unidentified ducks	90	4	0	4	24	**122**
Unidentified plover (*Charadrius* spp.)	0	0	0	21	0	**21**
Unidentified sandpiper	0	0	0	1	0	**1**
Iceland Gull (*Larus glaucoides*)	0	1	0	0	0	**1**
Great Black-backed Gull (*Larus marinus*)	4	31	88	64	10	**197**
Herring Gull (*Larus argentatus*)	24	64	330	348	33	**799**
Black-legged Kittiwake (*Rissa tridactyla*)	23	10	1	2964	35	**3033**
Unidentified gulls (*Larus* spp.)	42	307	318	3987	125	**4779**
Unidentified tern (*Sterna* spp.)	58	13	30	37	0	**138**

Appendix 2 (cont.)

Razorbill (*Alca torda*)	0	4	0	0	0	4
Common Murre (*Uria aalge*)	0	95	0	0	0	95
Unidentified murre (*Uria* spp.)	1224	35	8	11	11	1289
Black Guillemot (*Cepphus grylle*)	4	3	0	1	4	12
Atlantic Puffin (*Fratercula arctica*)	0	38	5	10	1	54
Unidentified alcid	261	32	3	25	8	329
American Crow (*Corvus brachyrhynchos*)	0	0	1	0	0	1
Finback Whale (*Balaenoptera physalus*)	0	0	0	2	0	2
Minke Whale (*Balaenoptera acutorostrata*)	0	0	0	10	0	10
Humpback Whale (*Megaptera novaeangliae*)	0	0	0	7	0	7
Unidentified whale	0	0	1	26	0	27
Unidentified dolphin	0	0	0	57	0	57
Unidenitified seal	1	0	0	0	0	1
Totals	**1791**	**715**	**883**	**7736**	**373**	**11498**

Appendix 3. List of all species and total numbers of individuals observed during land-based transects from May-November 1996. "-" indicates that no counts were made.

	Month										
	May		July		August		September		November		Totals
Species	NF	Lab	NF	Lab	NF	Lab	NF	Lab	NF	Lab	
Common Loon (*Gavia immer*)	0	0	34	2	0	0	0	0	0	0	**36**
Red-throated Loon (*Gavia stellata*)	0	0	4	0	0	0	0	0	0	0	**4**
Unidentified loon	0	0	10	5	0	0	0	0	0	0	**15**
Northern Gannet (*Sula bassens*)	0	0	123	34	16	0	18	5	3	0	**199**
Double-crested Cormorant (*Phalacrocorax auritus*)	0	0	0	0	0	0	0	0	1	0	**1**
Mallard (*Anas platyrhynchos*)	6	0	0	0	0	0	0	0	0	0	**6**
Common Eider (*Somateria mollissima*)	125	0	572	518	0	0	0	0	22	0	**1237**
White-winged Scoter (*Melanitta deglandi*)	0	0	89	73	0	0	0	0	2	0	**164**
Surf Scoter (*Melanitta perspicillata*)	0	0	6	0	0	0	0	0	0	0	**6**
Black Scoter (*Melanitta nigra*)	1	0	7	7	0	0	0	4	0	0	**19**
Unidentified eider	1	0	0	0	0	0	0	0	0	0	**1**
Unidentified scoter	0	0	2	0	0	0	0	0	0	0	**2**
Unidentified ducks	4	0	112	108	24	0	18	13	7	9	**295**
Red-breasted Merganser (*Mergus serrator*)	0	0	24	12	0	0	0	0	0	0	**36**
Unidentified merganser	0	0	2	0	0	0	3	3	0	0	**8**

Appendix 3. (cont.)

Osprey (*Pandion haliaetus*)	0	0	0	0	0	0	1	0	0	0	**1**
Unidentified hawk	0	0	0	0	2	0	0	0	0	0	**2**
Semipalmated Plover (*Charadrius semipalmatus*)	0	0	2	0	0	0	24	0	0	0	**26**
Unidentified plover (*Charadrius* spp.)	0	0	0	0	16	0	75	38	3	0	**132**
Whimbrel (*Numenius phaeopus*)	0	0	0	0	4	0	0	0	0	0	**4**
Yellowlegs spp. (*Tringa* spp.)	0	0	0	0	57	0	29	7	0	0	**93**
Spotted Sandpiper (*Actitis macularia*)	0	0	5	0	202	0	57	33	19	0	**316**
Ruddy Turnstone (*Arenaria interpres*)	0	0	0	0	0	0	0	0	27	0	**27**
White-rumped Sandpiper (*Calidris fuscicollis*)	0	0	0	0	121	0	0	0	0	0	**121**
Unidentified sandpiper	1	0	0	0	370	0	1	49	4	0	**425**
Unidentified jaeger	0	0	0	0	0	0	2	0	0	0	**2**
Ring-billed Gull (*Larus delawarensis*)	51	0	1	0	1	0	0	0	9	0	**61**
Glaucous Gull (*Larus hyperboreus*)	0	0	1	1	0	0	0	0	4	0	**6**
Iceland Gull (*Larus glaucoides*)	0	0	5	1	0	0	0	0	0	0	**6**
Great Black-backed Gull (*Larus marinus*)	12	22	585	23	329	0	168	31	31	53	**1254**
Herring Gull (*Larus argentatus*)	11	12	758	137	157	0	170	103	57	66	**1471**
Black-legged Kittiwake (*Rissa tridactyla*)	79	11	41	34	1	0	7	0	0	0	**173**
Unidentified hooded gull	0	0	0	0	0	0	0	0	5	0	**5**
Unidentified gulls (*Larus* spp.)	24	2	365	122	281	0	512	869	145	114	**2434**

Appendix 3. (cont.)

Unidentified tern (*Sterna* spp.)	2	0	199	8	27	0	66	42	0	0	344
Arctic Tern (*Sterna paradisaea*)	0	0	26	0	0	0	0	0	0	0	26
Common Murre (*Uria aalge*)	0	0	2	0	0	0	0	0	0	0	2
Unidentified murre (*Uria* spp.)	432	0	5	5	1	0	0	0	0	1	444
Razorbill (*Alca torda*)	0	0	10	10	0	0	0	0	0	0	20
Black Guillemot (*Cepphus grylle*)	2	0	3	1	0	0	0	0	0	0	6
Atlantic Puffin (*Fratercula arctica*)	6	0	24	24	0	0	0	0	0	1	55
Unidentified alcid	4	0	12	6	0	0	0	0	15	37	74
American Crow (*Corvus brachyrhynchos*)	1	0	0	0	22	0	0	0	18	0	41
Northern Raven (*Corvus corax*)	1	0	0	0	0	0	0	0	1	0	2
Unidentified whale	0	0	0	0	0	0	1	2	0	0	3
Totals	**761**	**47**	**3029**	**1131**	**1631**	**0**	**1152**	**1199**	**373**	**281**	**9604**

Appendix 4. Required increases (birds/5 min and % increases) in the mean counts of birds in east and west regions of each transect in order to obtain significant differences at the observed level of variance. Required increases apply to the higher of the east and west means for each transect. Means of zero indicate that no birds were seen in the region during the transect. Required increases of zero indicate significant differences between original mean counts. "-" indicates that no birds of the taxonomic group were observed during the transect.

Transect	Taxonomic Group	East (Mean ± 1 s.d.)	West (Mean ± 1 s.d.)	Required Increase (birds/5 min)	Required Increase (%)
1	*Uria* spp.	15.64 ± 19.79	0	0.75	4.8
	Larus spp.	0.21 ± 0.43	0.25 ± 0.50	0.75	300
	Alcidae	26.21 ± 30.10	0	6	22.9
	Laridae	0.21 ± 0.43	0.25 ± 0.50	0.75	300
2	*Uria* spp.	38.27 ± 40.64	0.67 ± 1.15	13.5	35.3
	Larus spp.	0	1.33 ± 2.31	0.5	37.6
	Alcidae	40.67 ± 41.28	1.33 ± 1.15	13	32.0
	Laridae	0	1.33 ± 2.31	0.25	37.5
3	*Uria* spp.	13.47 ± 17.98	0	9.5	70.5
	Larus spp.	0.13 ± 0.52	0	0.75	563
	Alcidae	16.33 ± 20.98	0	10	61.2
	Laridae	0.13 ± 0.52	0	0.75	563

Appendix 4. (cont.)

4	*Uria* spp.	5.43 ± 11.88	0	7.5	138
	Larus spp.	0.21 ± 0.58	0	0.5	233
	Alcidae	5.86 ± 12.02	0	7.25	124
	Laridae	1.29 ± 4.53	0	2.75	214
5	*Uria* spp.	6.21 ± 11.58	7.0 ± 11.49	13.25	189
	Larus spp.	0.93 ± 2.43	0	2	215
	Alcidae	6.21 ± 11.58	7.0 ± 11.49	13.25	189
	Laridae	1.07 ± 2.43	0	1.75	163
6	*Uria* spp.	2.20 ± 2.73	0	1.25	56.8
	Larus spp.	0.20 ± 0.56	1.0 ± 1.0	0.1	10.0
	Alcidae	2.60 ± 3.60	0	2	77.0
	Laridae	0.27 ± 0.59	9.0 ± 13.89	0.15	1.7
7	*Uria* spp.	3.0 ± 8.28	7.89 ± 19.99	10.5	13
	Larus spp.	2.22 ± 3.73	1.89 ± 2.15	2.75	124
	Alcidae	5.33 ± 8.08	12.67 ± 22.34	9.5	75.0
	Laridae	2.33 ± 3.67	1.89 ± 2.15	2.5	107
8	*Uria* spp.	0	0.56 ± 1.01	0.25	45.0
	Larus spp.	0.11 ± 0.33	0	0.1	90.1
	Alcidae	0	0.67 ± 1.32	0.25	37.5
	Laridae	0.11 ± 0.33	6.78 ± 19.96	7.5	111

Appendix 4. (cont.)

9	*Uria* spp.	0.11 ± 0.33	0	0.1	90.1
	Larus spp.	0.11 ± 0.33	0	0.1	90.1
	Alcidae	0.11 ± 0.33	0	0.1	90.1
	Laridae	0.33 ± 0.50	0	0.1	30.0
10	*Uria* spp.	0.47 ± 1.55	0	1.5	321
	Larus spp.	1.0 ± 2.88	0	1.75	175
	Alcidae	0.53 ± 1.55	0	1.5	281
	Laridae	8.07 ± 26.43	0	26	322
11	*Uria* spp.	0.71 ± 2.16	0	1.75	245
	Larus spp.	0.50 ± 0.94	2.25 ± 1.50	0.11	4.9
	Alcidae	0.71 ± 2.16	0	1.75	245
	Laridae	0.57 ± 0.94	2.25 ± 1.50	0.1	4.4
12	*Uria* spp.	0.07 ± 0.26	0	0.3	450
	Larus spp.	0.53 ± 0.99	0	0.75	141
	Alcidae	0.13 ± 0.35	0	0.4	300
	Laridae	0.53 ± 0.99	66.67 ± 115.47	1	1.5
13	*Uria* spp.	0.60 ± 0.83	0	0.4	66.7
	Larus spp.	0.67 ± 1.05	1.33 ± 0.58	0.65	48.8
	Alcidae	0.80 ± 0.86	0	0.3	37.5
	Laridae	0.73 ± 1.10	1.33 ± 0.58	0.75	56.3

Appendix 4. (cont.)

14	*Uria* spp.	0.19 ± 0.53	0	0.4	205
	Larus spp.	2.34 ± 2.28	32.27 ± 19.05	0	0
	Alcidae	0.26 ± 0.56	0.45 ± 0.91	0.6	132
	Laridae	2.92 ± 2.55	45.0 ± 34.29	0	0
15	*Uria* spp.	0.06 ± 0.23	0	0.2	333
	Larus spp.	11.66 ± 16.93	4.0 ± 6.35	11.2	96.1
	Alcidae	0.12 ± 0.31	0	0.2	166
	Laridae	14.01 ± 21.39	5.05 ± 6.26	15	107
16	*Uria* spp.	0	0	-	-
	Larus spp.	0.21 ± 0.58	0	0.45	210
	Alcidae	0	0	-	-
	Laridae	0.43 ± 0.76	0	0.4	93.3
17	*Uria* spp.	0	0.40 ± 0.89	0.15	37.5
	Larus spp.	0	1.20 ± 1.64	0.15	12.5
	Alcidae	0	0.80 ± 1.79	0.25	31.3
	Laridae	0	8.2 ± 15.06	0.2	2.4
18	*Uria* spp.	0	0	-	-
	Larus spp.	0.36 ± 0.58	0.15 ± 0.36	0.4	110
	Alcidae	0	0	-	-
	Laridae	8.74 ± 25.97	0.15 ± 0.36	15	172

Appendix 4. (cont.)

19	*Uria* spp.	0	0	-	-
	Larus spp.	0	0.18 ± 0.40	0.25	140
	Alcidae	0	0.36 ± 0.80	0.25	70.1
	Laridae	0.21 ± 0.39	7.67 ± 10.73	0.2	2.6
20	*Uria* spp.	0.14 ± 0.49	0	0.35	258
	Larus spp.	0.27 ± 0.75	1.06 ± 1.45	0.75	70.8
	Alcidae	0.14 ± 0.49	0	0.35	258
	Laridae	0.81 ± 1.27	2.82 ± 1.58	0	0
21	*Uria* spp.	0	0	-	-
	Larus spp.	0.50 ± 0.85	0.29 ± 0.70	1	200
	Alcidae	0	0	-	-
	Laridae	0.64 ± 0.91	0.29 ± 0.70	1	155
22	*Uria* spp.	0	0	-	-
	Larus spp.	0.96 ± 1.57	1.86 ± 3.95	2.5	135
	Alcidae	0	0	-	-
	Laridae	1.80 ± 2.70	65.8 ± 153.0	22.5	34.2
23	*Uria* spp.	0.07 ± 0.25	0	0.2	23.3
	Larus spp.	0.86 ± 1.10	4.86 ± 11.49	3	61.7
	Alcidae	0.50 ± 1.24	0	0.65	130
	Laridae	26.87 ± 59.49	6.58 ± 15.69	33	123

Appendix 4. (cont.)

24	*Uria* spp.	0.07 ± 0.25	0	0.15	210
	Larus spp.	0.29 ± 0.76	0.57 ± 0.70	0.5	87.4
	Alcidae	0.29 ± 0.67	0	0.4	140
	Laridae	0.70 ± 1.10	218.7 ± 524.4	92.5	42.3
25	*Uria* spp.	0	0	-	-
	Larus spp.	0	4.28 ± 11.33	3	70.0
	Alcidae	0.16 ± 0.53	0	0.35	218
	Laridae	26.21 ± 71.53	6.55 ± 14.40	38	145
26	*Uria* spp.	0	0	-	-
	Larus spp.	2.83 ± 7.32	20.52 ± 35.46	7.5	36.5
	Alcidae	0	0.52 ± 1.47	0.45	86.5
	Laridae	4.42 ± 10.53	43.13 ± 79.43	15	34.8
27	*Uria* spp.	0	0	-	-
	Larus spp.	1.17 ± 2.61	0.21 ± 0.59	0.2	17.1
	Alcidae	0.25 ± 0.56	0	0.1	40
	Laridae	53.67 ± 98.61	0.62 ± 1.16	21	39.1
28	*Uria* spp.	0.43 ± 1.00	0	0.4	93.3
	Larus spp.	0.93 ± 1.34	0.57 ± 0.70	0.9	96.9
	Alcidae	0.64 ± 1.10	0	0.35	54.4
	Laridae	1.07 ± 1.33	0.72 ± 0.65	0.9	84.0

Appendix 4. (cont.)

29	*Uria* spp.	0.08 ± 0.25	0.12 ± 0.32	0.15	125
	Larus spp.	0.31 ± 0.78	0.24 ± 0.41	0.65	212
	Alcidae	0.08 ± 0.25	0.12 ± 0.32	0.15	125
	Laridae	0.31 ± 0.78	0.24 ± 0.41	0.65	212
30	*Uria* spp.	0.10 ± 0.30	0	0.13	129
	Larus spp.	0.10 ± 0.30	1.01 ± 1.47	0.15	14.9
	Alcidae	0.10 ± 0.30	0.61 ± 1.29	0.4	70.0
	Laridae	0.20 ± 0.40	1.01 ± 1.47	0.28	27.7
31	*Uria* spp.	0.10 ± 0.30	0	0.13	129
	Larus spp.	0.10 ± 0.30	1.01 ± 1.47	0.15	14.9
	Alcidae	0.10 ± 0.30	0.61 ± 1.29	0.4	70.0
	Laridae	0.20 ± 0.40	1.01 ± 1.47	0.28	27.7
32	*Uria* spp.	0.19 ± 0.58	0	0.2	103
	Larus spp.	0.10 ± 0.29	0	0.11	113
	Alcidae	0.19 ± 0.58	0	0.2	103
	Laridae	0.10 ± 0.29	0	0.11	113
33	*Uria* spp.	0	0	-	-
	Larus spp.	0.60 ± 1.30	1.08 ± 1.86	1.5	139
	Alcidae	0	0.13 ± 0.42	0.3	267
	Laridae	0.60 ± 1.30	2.98 ± 8.06	6.5	218

Appendix 4. (cont.)

34	*Uria* spp.	0	0	-	-
	Larus spp.	0.15 ± 0.32	1.03 ± 2.92	2	194
	Alcidae	0	0.09 ± 0.27	0.25	267
	Laridae	0.15 ± 0.32	1.03 ± 2.92	2	194
35	*Uria* spp.	0	0	-	-
	Larus spp.	0.67 ± 0.90	0.66 ± 0.84	1.25	185
	Alcidae	0.30 ± 0.52	1.31 ± 2.19	0.75	57.2
	Laridae	0.67 ± 0.90	0.66 ± 0.84	1.25	185
36	*Uria* spp.	0	0	-	-
	Larus spp.	0.76 ± 1.01	0.74 ± 0.95	1.25	165
	Alcidae	0.34 ± 0.59	1.47 ± 2.45	1	67.9
	Laridae	0.76 ± 1.01	0.74 ± 0.95	1.25	165